HIGHWAY RESEARCH REPORT

BLAST FURNACE SLAG FOR USE AS AGGREGATE

67-10

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 645169

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

Final Research Report
M & R No. 645169

September, 1967

Mr. L. R. Gillis
Assistant State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

BLAST FURNACE SLAG FOR
USE AS AGGREGATE

Donald L. Spellman
Principal Investigator

Work done under the general direction of the Concrete Section

Petrographic analysis performed by the Foundation Section

Asphalt Concrete, Cement Treated Base, and Untreated Base study performed by the Pavement Section

All under the immediate supervision of:

W. H. Ames and D. R. Smith

Report prepared by:

J. H. Coan and John F. Boss

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

Final Research Report

[illegible]

Management [illegible]

[illegible]

[illegible] Treated Rice Straw

[illegible] formed by the Department [illegible]

[illegible]

[illegible] Statistics and Research [illegible]

Reference: Spellman, D. L. "Blast Furnace Slag for Use as Aggregate", State of California, Department of Public Works, Division of Highways, Materials and Research Department. Research Report No. 645169, September, 1967.

Abstract: An air-cooled, blast furnace slag aggregate produced in California was tested for possible use in portland cement concrete, asphalt concrete, cement treated base, and untreated base. Mixes of variable portland cement content and air entrainment made with coarse slag aggregate and natural sand were compared with a control mix of natural aggregate for compressive strength, flexural strength, modulus of elasticity and shrinkage characteristics.

A 1/2-inch maximum size aggregate asphalt mix was designed using slag aggregate and tested according to California design method. Various mixes of cement treated base were tested for strength and durability. The slag aggregate was tested for compliance with California specifications covering untreated aggregate base.

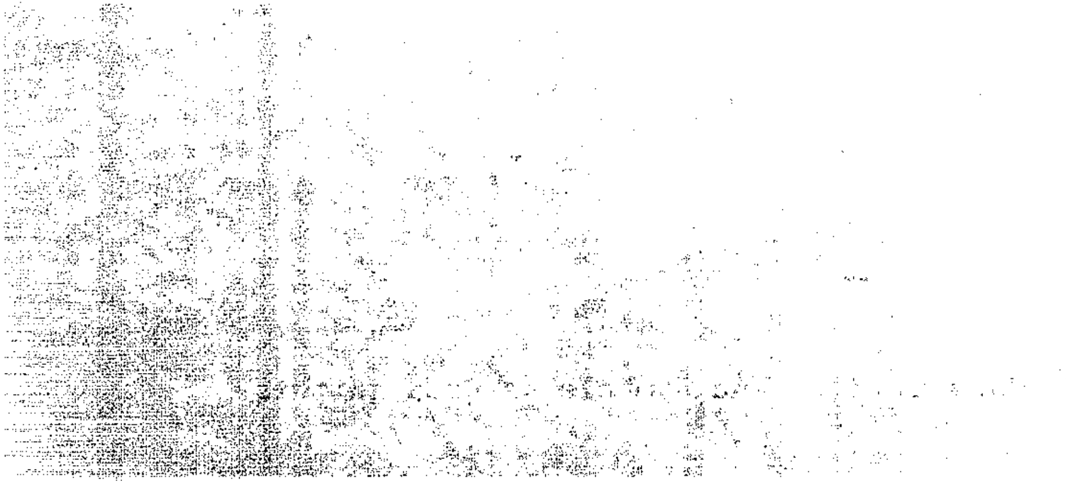
Blast furnace slag aggregate was, with certain exceptions, found to be satisfactory for use. Although no corrosion tests have been made, the chemical analysis indicates the presence of potentially corrosive compounds; therefore, the slag aggregate tested should not be used in prestressed concrete members until the potential corrosive properties have been thoroughly evaluated.

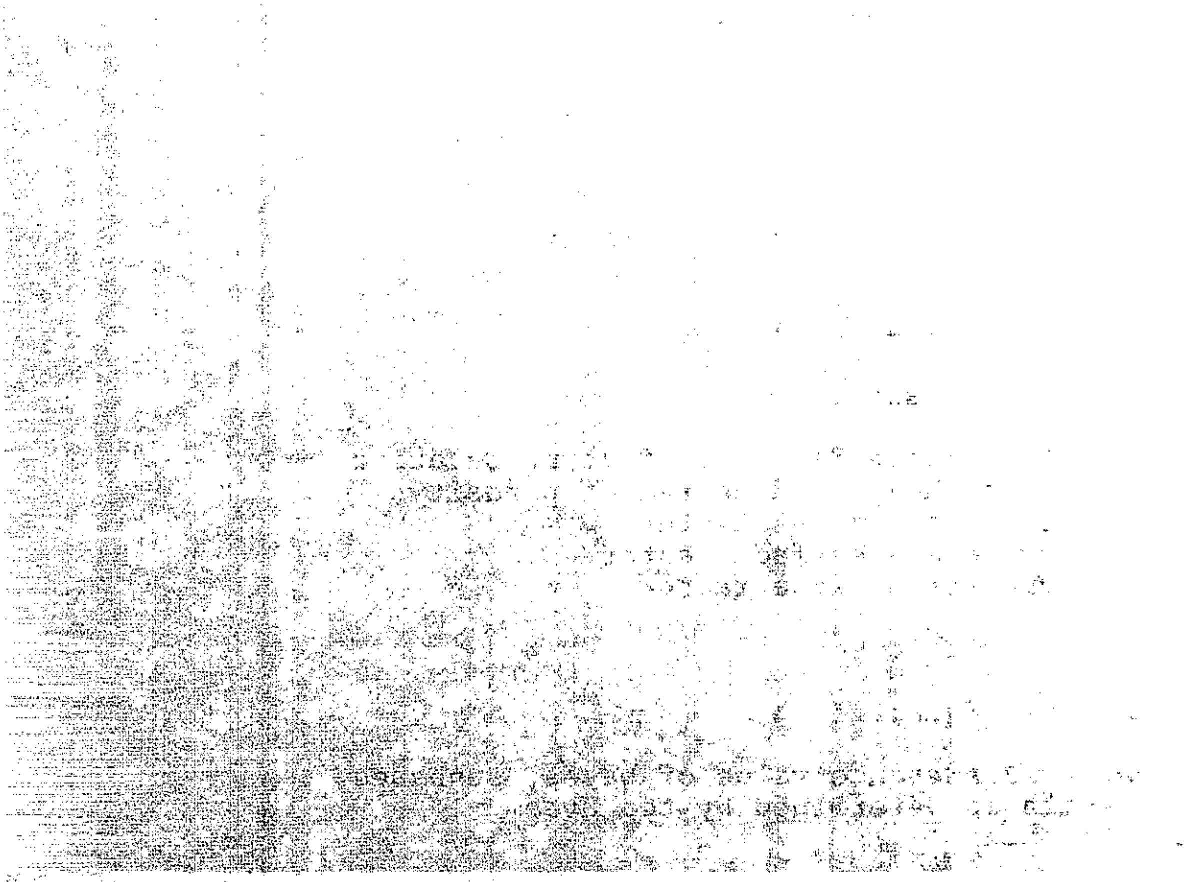
Key Words: Aggregates, slags, slag coarse aggregate, portland cement concrete, asphaltic concrete, aggregate testing, compressive strength, flexural strength, modulus of elasticity, shrinkage, concretes, cement treated base, cement content, air entrainment.

NOTATIONS

List of abbreviations and symbols as used in this report:

CKE	California Kerosene Equivalent
C	CKE of aggregate passing 3/8-inch screen and retained on No. 4 screen
F	CKE of aggregate passing No. 4 sieve
CTB	Cement Treated Base
Dc	Durability Factor - Coarse Aggregate
Df	" " Fine "
DTA	Differential Thermal Analysis
E	Modulus of Elasticity
K	Aggregate Surface Factor indicating relative particle roughness and degree of porosity
K_f	Fine aggregate surface factor
K_c	Coarse aggregate surface factor
K_m	Mean aggregate surface factor
PCF	Pounds per Cubic Foot
PSI	Pounds per Square Inch
R	R-value. Resistance value of bases, subbases, and soils as determined by the Hveem Stabilometer
SE	Sand Equivalent as determined by Test Method No. Calif. 217
SSD	Saturated Surface Dry
W/C	Water-cement Ratio





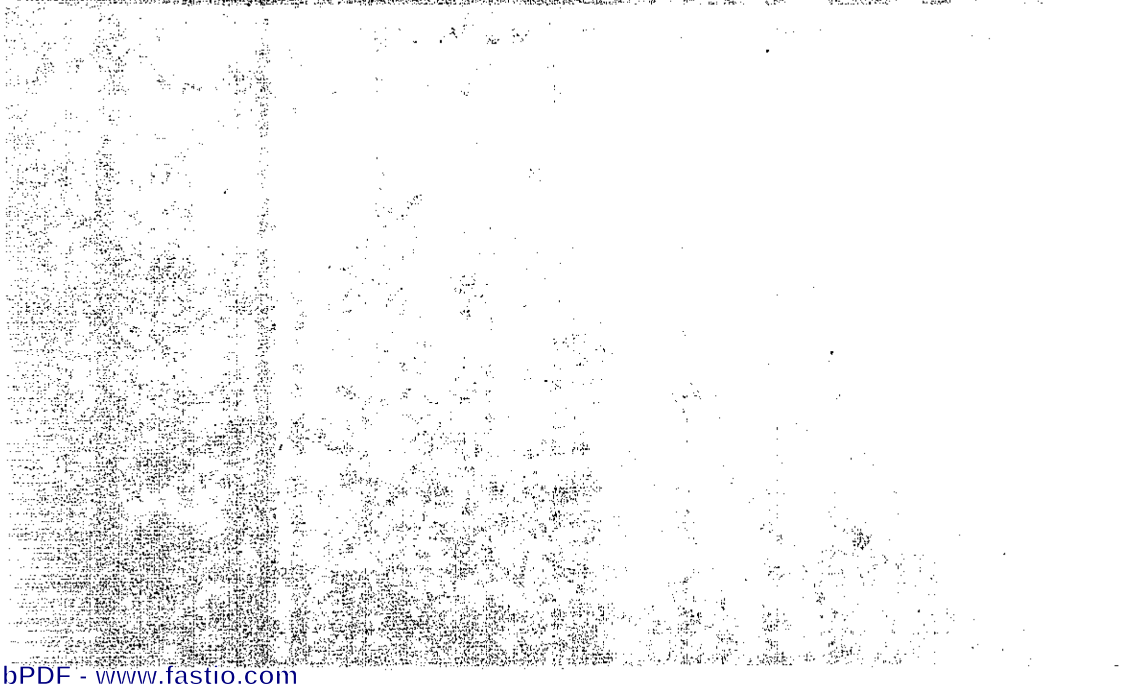


TABLE OF CONTENTS

BLAST FURNACE SLAG FOR USE AS AGGREGATE

INTRODUCTION

In recent years, there has been a reported increase in the use of air-cooled blast furnace slag aggregates. The material is defined as "the non-metallic product, consisting essentially of silicates and alumino-silicates of lime and of other bases, which is developed simultaneously with iron in a blast furnace."[1*] Therefore, it has been produced commercially only near steel producing centers.

Near the end of 1967, a large modern processing plant in California will be producing slag aggregates. They have been proposed for use in California highway work. In 1944, a limited testing program was conducted by the State of California, Materials and Research Department on slag aggregate.[2] The material was judged acceptable for use in highway work based on specifications in effect at the time. The present program was set up to expand upon the previous one, and to compare its properties with current specification requirements for aggregate.

*Refers to reference listed at end of report.

CONCLUSIONS

The slag tested was found, with certain exceptions as discussed below, to meet present California test requirements for aggregate for use in portland cement concrete, asphalt concrete, cement treated base, and untreated base.

A. Portland Cement Concrete

Based on laboratory tests, a good workable slag aggregate concrete mix with acceptable strength and shrinkage qualities can be made using a natural sand and about 4 to 5 percent air entrainment with an increase of about 1/2-sack of cement per cubic yard more than a comparable non-air-entrained concrete. A 5-1/2-sack mix with 4 percent entrained air possessed good placing and finishing qualities, and should produce a pavement of adequate strength.

The Los Angeles Abrasion Loss of the material tested was high, but met current requirements. There is some evidence that LA Abrasion Loss for this type of aggregate is generally high.

It was found advantageous to prewet the slag aggregate to secure a near SSD condition before incorporating it into a mix since the slag aggregate has a high absorption (5 to 6 percent). Prewetting should be a requirement for portland cement concrete production to prevent loss of slump while transporting, placing and finishing.

Since the slag aggregate tested is a manufactured product taken directly from the cooling bed next to the blast furnaces to the crusher, its cleanness was very high and contamination very low. Under normal circumstances, it would not have to be washed to meet cleanness requirements. All the slag aggregates used in the tests were unwashed samples taken directly from an existing plant being used to process aggregate for other uses.

Until the potential corrosive properties of this material can be evaluated, slag aggregate should not be used in any prestressed concrete construction.

B. Asphalt Concrete

For the mix design tested, the results indicated an acceptable asphalt concrete. Very little degradation was noted when extracted grading was compared with design grading. This type of aggregate has a high K_c value (surface constant) which represents the total effect of superficial area, the aggregate absorptive properties and surface roughness. A relatively high asphalt content was required, but satisfactory stabilometer values were obtained.

Present California Highway specifications for the Los Angeles Rattler Loss at 100 revolutions and for limit on K-Factors would, without some modification, preclude the use of this material in asphalt concrete.

C. Cement Treated Base and Untreated Base

Slag aggregate exhibited satisfactory properties when tested as a treated or untreated base material. Again, the aggregate should be prewetted to SSD to insure consistant qualities. Strengthwise, the CTB compares very favorably with conventional CTB, and wet-dry or freeze-thaw cycles affect it little, if any. Although the material was slightly out of grading (3/4" should be 90-100% passing), this might be corrected very easily at the crusher plant. All other properties of the material tested exceed current California highway specifications.

SAMPLING, TESTING AND TEST RESULTS

Samples were taken by a representative of the Materials and Research Department from stockpiles in the yard of a small processing plant currently operated primarily for the production of roofing chips and railroad ballast. The material produced by this plant was from the same daily output of a blast furnace from which future slag will be supplied, and future supplies should be basically the same in all respects. The sample of coarse aggregate was separated into individual sizes at the Sacramento Laboratory and recombined for specific testing purposes.

Other materials used in various phases of this testing program were as follows:

Natural fines:	American River (Lab Stock)
Control mix aggregate:	American River (Lab Stock)
Cement:	Type II Modified (Lab Stock)
Air-entraining Agent:	Vinsol Resin
Asphalt:	85-100 Penetration

The slag aggregate was examined petrographically, chemically, and physically. (Tables 1, 2, and 3.) The concrete series of tests included tests for compressive and flexural strengths, for compressive modulus of elasticity, and for shrinkage characteristics (Table 4). Mixes with different cement factors and air contents were compared with a control mix of natural aggregate.

The asphalt test series consisted of the design and testing of a typical 1/2-inch maximum aggregate size asphalt concrete mix made with the slag aggregate (Table 5).

The aggregate as used for cement treated base was tested for density and compressive strength at several moisture and cement contents, and also for resistance to wet-dry and freeze-thaw cycles at one given moisture and cement content (Table 6).

The aggregate for use in untreated base was tested for aggregate grading, R-value, sand equivalent, and durability (Table 7).

CLOSURE

The results of this test program show that the slag aggregate tested can be used with certain restrictions or conditions for portland cement concrete, asphalt concrete, cement treated base, and untreated base. Limits for the LA Rattler loss at 100 revolutions and for surface constants for asphalt concrete would have to be revised to take into consideration the special surface and absorption characteristics of slag aggregate.

A possible advantage of using this material is the relatively low unit weight of portland cement concrete made with it (approximately 135 pounds per cubic foot). This quality, in conjunction with its good strength and low shrinkage characteristics, might be useful in reducing dead loads in structural design.

REFERENCES

1. 1961 Book of ASTM Standards, Standard Definitions of Terms Relating to Concrete and Concrete Aggregates, ASTM C 125-58, Part IV, American Society of Testing and Materials, Philadelphia, Pa., 1961, p. 646

2. Reported in letter T. E. Stanton to R. M. Gillis, July 13, 1944

3. Proceedings, ASTM 1966, American Society of Testing and Materials, Philadelphia, Pa., 1966, p. 252

TABLE 1

Physical Properties of Slag Aggregate

	Primary Size		
	1-1/2"	3/4"	Combined Gradation
Sodium Sulfate Soundness Loss*	2%	2%	
Specific Gravity	2.28	2.31	
Absorption	6.2%	5.0%	
Cleanness Value**	86	89	88
LA Rattler (500 Rev.), % Loss			41

* Calif. Test Method 214
**Calif. Test Method 227

TABLE 2

Mineral Composition

1. Akermanite
2. Merwinite
3. Enstatite
4. Gehlenite
5. Hardstonite
6. Monticellite
7. Calcium cyanide
8. Ba Zn Germanate
9. Kal SiO4
10. Plagioclase

The above were determined by X-ray diffraction, D.T.A., and petrographic examination

TABLE 3

Chemical Analysis

Material			Percent By Weight
Carbonates	as	CO_2	0.60
Sulphates	as	SO_3	0.11
Chlorides	as	Cl	0.02
Sulphides	as	S	0.65
Phosphates	as	P_2O_5	Nil
Silica	as	SiO_2	35.0
Alumina	as	Al_2O_3	10.3
Ferrous Iron	as	Fe	0.25
Lime	as	CaO	35.8
Magnesia	as	MgO	14.6
Manganese	as	Mn	1.23
Potassium	as	K_2O	0.92
Sodium	as	Na_2O	0.52
Cyanide	as	CN	less than 0.01
			100.01

TABLE 4

Portland Cement Concrete Properties

	Control	Fontana Slag			
Cement (Sks./Cu.Yd.)	5	5	5 AE*	5-1/2 AE	6 AE
Air Content (%)	1.3	1.8	4.3	5.1	5.0
Slump, Inches	2.0	2.6	2.8	2.8	2.0
W/C Net, Lbs./Sk.	47.4	47.5	45.5	40.7	37.9
W/C Total, Lbs./Sk.	57.0	73.1	70.5	63.3	58.3
% of Aggregate Passing No. 4	38	40	39	38	37
14-day Compr. Strength, psi	3705	4045	3565	4070	4550
28-day " " "	4680	4760	4185	4840	5230
14-day Flexural Strength, psi	530	615	555	630	630
% of Control (Flexural)	100	115	104	118	118
Comp. E at 28 days (X 10^6), psi	5.71	5.52	5.00	5.16	5.16
% Relative Shrinkage:					
14 days	100	68	71	75	71
28 days	100	72	82	79	79

*Air Entrained

TABLE 5

Asphalt Concrete Properties

Grading		Other Aggregate Properties	
Size	% Passing By Weight	Surface Area	37.2 sq.ft./lb.
3/4"	100	Bitumen Used	85-100 Pen.
1/2"	100	CKE Values: F	3.40
3/8"	90	C	6.55
No. 4	70	Theoretical Bitumen Ratio	6.5%
No. 8	51	K_c	2.3
No. 16	40	K_f	1.2
No. 30	30	K_m	1.4
No. 50	20	LA Rattler, 100 Rev.	11% Loss
No. 100	12	" " 500 "	45% Loss
No. 200	7	Sodium Sulfate Soundness	2% Loss
		Film Stripping	None
		Sand Equivalent	87
		Surface Abrasion	0

Asphalt Mix Properties

Specimen	A	B	C	D	E
Temperature, °F	140	140	140	140	140
Bitumen Ratio, %	6.0	6.5	7.0	7.5	8.0
Specific Gravity Briq.	2.23	2.24	2.25	2.28	2.28
Stabilometer	47	45	50	47	50
Cohesiometer	119	112	164	164	211
Voids, %	7.1	5.8	4.9	2.9	2.0
Swell, In. (24 hours)	.001	.001	-	-	-
Permeability, ml/24 hrs.	500	500	-	-	-
Susceptibility to Moisture Vapor:					
Hours	75	75			
Moisture Absorbed, %	0.4	0.5			
Stabilometer	48	45			
Cohesion	287	341			
Bitumen Ratio	7.0	7.0			
Sp. Gr. Briq.	2.26	2.24			

TABLE 6

Cement Treated Base

Percent Moist.	Percent Cement	Density (pcf)	Compr. Strength (psi)
8.3	2.0	120	486
8.3	4.0	122	1043
8.3	6.0	122	1348
7.7	4.0	122	1115
8.3	4.0	122	1138
8.6	4.0	122	1122
Wet and Dry (12 Cycles) In water 5 hours, 140°F Oven 42 hours			
8.3	4.0	122	1272
8.3	4.0	122	1152
% volume change for both specimens - zero Condition of specimens - excellent			
Freeze-Thaw (12 Cycles) Freeze - 24 hours; Thaw - 24 hours			
8.3	4.0	122	1240
8.3	4.0	122	1212
% volume change for both specimens - zero Condition of specimens - excellent			

TABLE 7

Aggregate (Untreated) Base

Sieve Size	Percent Passing	
1-1/2"	100	R = 83
3/4"	83	SE = 72
No. 4	36	Df = 87
No. 30	14	Dc = 87
No. 200	5	